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THE METAL CONSTRUCTION OF AIRPLANES - ITS ADVANTAGES - ITS PRESENT STATE - ITS FUTURE

By M. E. DeWoitine

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By M. E. DeWoitine.

I have been particularly touched by the honor done me when your President asked me to come and give a lecture before your Society. By thus inviting foreign designers to participate in your work you foster exchange of ideas, which can only be profitable to the entire sphere of aeronautics; you establish bonds of friendship which should exist between English and French designers who, after four years of collaboration, have each taken their own particular orientation.

Each country, in fact, possesses of necessity the technique which is required by its natural needs, its local resources and its industrial means. However, it is a good thing that these technical questions should not be forgotten, and your meetings have greatly contributed to the progress of each party concerned.

For my own part, I have turned towards the construction of airplanes in duralumin, which seems to be one of the most marked tendencies in modern French construction. I believe I shall be doing some useful work in bringing before you the reasons which have led French designers to this particular development, the

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results which they have obtained, and the hopes for the future which they base on this class of construction.

First, to fully understand the reasons which have urged us towards metal construction, we must place before ourselves the problem of the airplane as it is actually presented before our eyes, that is to say, the search for better efficiency. I mean here by "efficiency," the proportion of useful load carried by an airplane with a given speed and a determined power.

This definition is very general, and one can conceive some type of airplane which, by reason of a particular duty, necessitates search for special qualities incompatible with the aforementioned idea of efficiency.

However, the improvement of the general qualities of the airplane results in progress simultaneously realized, in aerodynamic form, in the motive power units, and in the quality of the "construction," as it is called.

Since the wind channel has been used for the study of sections and for scale models of airplanes, data has been collected as complete as one could wish. The relatively recent study of thick sections, although bringing a new element into the question, has not really sensibly modified the technique of wing sections.

If one plotted on the same graph the polar curves of the best-known wings, one would see that all these curves lie in an enveloping curve, which would then be the polar curve of the

ideal wing. One would see that, except for a discovery coming to upset our conceptions in aerodynamical matters, it seems difficult to hope for progress, even at all perceptible, in the outline of the sections of wings. For each particular application of the airplane a well-informed designer will always find a well-adapted series of sections, having excellent efficiency, and of which the results will be approximately equivalent.

Indeed, the interest in thick wings lies, in our opinion, less in their inherent properties than in their ability to favor the construction of high efficiency wing structures, in which the almost complete suppression of exterior bracing reduces to a minimum the resistance to forward motion. The advantage of such wing structures is not a discovery; their realization was hardly possible with thin wings, since their thickness does not permit a sufficiently rigid construction. The employment of thick wings has simply permitted one to adopt in better conditions of construction the already ancient idea of the cantilever wing. But for the complete airplane, as for the wing itself, we are very near the limit of possibilities, and it is therefore somewhere else that we must look for progress.

Neither is it in the motive unit itself that one can hope to get any appreciable gain. If the return to air-cooled engines, such as the "Jupiter" and the "Jaguar," for example, has been the source of new and interesting realizations, it is

no less of importance to remark that the four-cycle engine, so universally employed, has arrived at a high state of perfection, and that if there still remains much to be done in research for endurance and safety, it does not seem possible to hope for the reduction, to any appreciable extent, of the gross power and the consumption per horsepower. The "Curtis" or "Hispano" engines, which have made speed records possible, are exceptionally advanced engines, which seem to represent the limit of present possibilities. If, therefore, it is neither in the efficiency of the wing structures, nor in the weight of the motive unit, that the aeronautical engineer of today can hope to find the source of a better production, it is in the reduction of constructional weight that he is bound to seek this necessary improvement.

Some designers have thought they would obtain this by lowering the factors of safety. Luckily, Government control has intervened to limit such initiative, which might be dangerous, and, to our mind, the work undertaken by the S.I.N.A. presents, in this respect, a vital interest. In the different countries the technical services, profiting by their war experience, have fixed upon a standard relative to the load to be placed upon wing structures.

This standard is established by formulas or empirical laws, which all, nevertheless, lead to similar figures for different types of airplanes, and it seems indispensable to fix a gener-

ally recognized minimum below which one must not go.

In France, the tendency would rather have been to increase the rigor of constructional rules, and it is criticizing no one to recall that recent French machines, examined consistently with such rules, have very high factors of safety, tested out by very severe sand tests, such as, for example, my fighter machine D.1.C.1., with a 300 HP. Hispano, of which the wing structure has undergone, without any permanent deformation, a load on the under surface corresponding to a coefficient of 16. Such figures may seem somewhat exaggerated, but they could not be much lowered without risking the safety of the airplane.

To sum up, as we are limited on the question of sections, in the choice of engines, and in the coefficients of loading, the designer must, in our opinion, look towards the choice and method of working of material to obtain the reduction of dead weight, and, in consequence, the achivement of the desired results.

The question of materials to use is the first, then, to be considered - the choice being limited to wood and metal. This question arose in the very first days of aviation, and the two methods of construction have been experimented upon simultaneously. In France, Clement, Voisin, Schmidt, Esnault-Pelleterie (to quote only the best-known) have largely used steel in the manufacture of wings and fuselages.

Notwithstanding the results obtained, we must remember that metal was rapidly abandoned, and that the use of wood was not long in becoming general practice. For what reasons? To our idea, it was first due to the ease of manipulation. Wood is by nature essentially a material for new industries; light, easy to work and assemble, it is a material essentially ideal for the inventor, who (without wishing to diminish their merit) obtained results with but little design and calculation. The forces supporting an airplane in flight were but little known; the methods of calculating surfaces were not fixed, there scarcely existed aerodynamical laboratories, and wood alone permitted the direct realization in the works of rapid modifications which were necessitated by the results of tests. Besides, being given the dimensions of typical airplanes, the use of ordinary steels would have resulted in prohibitive weights, and, as the light alloys of aluminum were unknown, metal could therefore gain no headway.

Finally, when one recalls the engines which were used in the very first flights, one realizes that every effort had primarily to be devoted to perfecting these, and that the first airplane constructors had to leave the improvement of wing structures until afterwards.

Nevertheless, if one makes a rapid comparison of densities, and the mechanical characteristics of different materials which could enter into the construction of the framework of airplanes,

it certainly appears as though the advantage would decidedly be with metal.

Density of woods used in aviation varies from .5 to 1.2, and their workable limit hardly exceeds 3 kilograms. There should be gain in weight by using duralumin, of which the density is 2.9 and the working limit 28 kilograms, or steel at 95 kilograms, despite its density of 7.8. Under such conditions, with equal weight, steel or duralumin should be 1½ times to twice as strong as, for example, spruce.

In spite of these à priori advantages, many other elements enter into a complete discussion of choice of material, and it is the reason why this question is so controversial. We are going to take up the discussion more completely, and with the arguments which made me lean towards duralumin at the time when I thought of building my first "fighter." I say decidedly that, after the five years' experience I have had with duralumin, these arguments have, in my opinion, retained their weight.

Let us see, first of all, what are the advantages and disadvantages of wood. We have already spoken of its advantages from the point of view of easy working. They are useful in greatly simplifying the study of prototypes. In such a study it is actually possible to achieve the construction without actually having carried out all the details of design; working is much simplified and only calls for a few non-costly wood-

working machines. Furthermore, the actual workmanship itself of wood-workers is less onerous than that of specialized mechanics, and this work can frequently make up the deficiency in lack of precision in the laying-out of the parts. That is why, even in France, many large airplanes are still constructed of wood, especially those which are going to be produced in limited numbers.

Its advantages are again found in production, although less marked, and we must recognize for the time being at least, that wooden airplanes in numbers cost but little less than identical airplanes in metal. This difference will become less, no doubt, when metal airplanes are made in large numbers, which may not yet be the case, still, this consideration has value only if one neglects smashes, and we reckon, quite justly, that one of the biggest faults of wood is in its ageing and in its difficulty of storage.

On the other hand, the disadvantages of wood are numerous. First of all, even the choice of wood for aviation purposes is a delicate matter. No mechanical test can, as in the case of metal, guarantee the quality of a whole supply; the not inconsiderable variations in density and strength of wood of the same source, complicate the study and necessitate great margins of safety.

These same variations occur again in a machined wooden part as the wood is ageing, and varnishing does not always give sufficient protection against the effects of the atmosphere.

Another disadvantage, and, in my opinion, more important, remains in the fact that the assembly of wooden pieces can only be done by gluing. Besides this, glues, being organic matter, decompose with time, and the examination of airplanes stored for a number of years, has frequently disclosed the complete disappearance of such glue which had been utilized in assembly. No protection can stop this alteration, and there is, besides, a grave danger in the fact that any inspection of it is impossible.

On the other hand, the manufacture of wooden airplanes in numbers reveals irregularities in performance which are due primarily to the material used. Really, the irregularity in the density of wood is also felt in the weight of airplanes where made in numbers. Besides, the outer dimensions of pieces, in spite of a regular control as to their conformity to the drawing, must necessarily be passed with a considerable tolerance, which consequently means differences in weight not inconsiderable in a series of airplanes.

Finally, construction in wood leads necessarily to a heterogeneous construction, covering with fabric, cross struts, and bracing wires, and this use of different materials precludes all idea of a uniform modulus of elasticity for the whole airplane, which also compels the designer to adhere to extremely high coefficients of safety.

The assembly of these various elements is done by the inter-

mediary of metal fittings, of which the connections to the principal members are liable to develop play after a certain time in service.

By this one is led to construct some assemblies with loose joints, in which truing-up plays a leading part, and which can only be carried out by specialized workmen. This adjustment is subject to frequent revision, which is as difficult as the original rigging of the new machine. To remedy this disadvantage, Fokker, Bernard and Curtiss have eliminated the flexible elements of the woodwork in using three-ply coverings, but this generally leads to extra weight (which cannot be permitted in machines built for speed), or to making dangerous sacrifices in the factor of safety.

With metal the greater part of these disadvantages disappears. In whatever form one uses it, metal has always constant mechanical characteristics, easily controlled, for the whole of a batch.

Assemblies by riveting, even by soldering, are easily controlled, and little altered by age.

In consequence, storage presents no disadvantages, which is particularly interesting from a military point of view. Relatively simple precautions can assure the constancy of metal, above all when it appertains to airplanes subjected to the action of salt air.

On the other hand, although opinion differs on the sub-

ject, I personally consider that the repair of a metal airplane is often easier than that of one built of wood. At the last French Aeronautical Exhibition I showed on my stand a prototype fighter machine which had then completed more than 350 hours' flying, and which had had a serious smash during a test being made by Rabatel for the Lamblin Cup. A wooden machine would, without a doubt, have been completely put out of use, while in my works the repairs were carried out easily, and the airplane was thus able to be used for flying once more.

An examination made of several metal machines in France after more than 100 hours' flying (Liore Cam - Breguet 19 A.2 De Woitine C.1) has distinctly shown the qualities of durability of metal and metal assemblies.

The fact of being able to replace by riveting, fatigued portions of the structure, further completes this durability, and would be of great importance in a commercial venture, or even in military squadrons possessing the necessary tools and experienced workers.

Again, metal alone permits of a truly homogeneous construction, of which each part can be exactly calculated, and of the accomplishment of an assemblage having one similar elastic limit, which allows, owing to the knowledge of the forces in flight, a very accurate solution of the problem, and reduction in the margin of safety. The uncertainty, from the point of view of the total strength of an airplane, resulting from the use of

materials of widely differing moduli of elasticity, which exists in wooden construction, would disappear in an all-metal machine, and would permit of the reduction, without danger, of the actually admitted factors of safety.

From the point of view of production in large quantities, metal construction, with its jigs for interchangeability, its precise process of working, assures an exactitude in dimensions to which wood could not pretend to make any claims on its own behalf. Thus, fighters of the type constructed by the "Societe d'Emboutissage et de Constructions Mecaniques" weigh, all of them, exactly the same, besides being some kilograms less than the prototype, and have given no trouble during rigging, as is so often found with wooden machines. From this a uniformity of flying qualities results, which has not always been the case with wooden airplanes built in numbers.

On the other hand, these advantages bring in some difficulties which cannot be denied, and before which, quite a number of constructors have drawn back.

First, one must not contemplate the putting in hand of an all-metal airplane until the details of the smallest parts have been entirely laid out on paper. This would lead to such waste that no workshop mechanic could rectify.

All-metal construction, therefore, necessitates an important designer's office capable of going into the utmost detail, and the establishment of a means of complete execution before

any realization, except the indispensable study of structure details, and comparative tests giving certain bases from which to start off.

Once the design is concluded, a design of which the method of construction is imposed by the plant one possesses, the realization of the prototype is definite, and no error is permitted.

From this there results a higher cost of the prototype, due to the costs of design and preliminary tests rather than the first cost of materials.

Finally, the creation of the prototype necessitates, if one has taken the precaution of considering production in large quantities, the provision of preliminary tools of a type suitable for this airplane only. These tools are produced by very accurate workmanship, and there again, the cost of an initial design is very heavy. It is true that these costs will become less as there begins to exist a surer technique of all-metal construction, and when a certain standardization has become established. It is in the research of this technique that the constructor should converge all his efforts, and on his work its possibilities of ultimate realization will depend.

For airplanes made in large numbers these disadvantages are spread over, and are largely compensated for by a better conservation of material.

In any case, if one is inclined to find industrial conceptions which can be applied to the work, such as drop-forging,

spinning, shearing, etc., the price comes down rapidly with increase of production, so much so that one needs less and less specialized workers in order to employ as much as possible - for example - female labor. It is with this direct idea that I have been guided, and with M. Amiot, the Director of the S.C.E.M., in the putting in hand of my fighter machines, and it is from this moment already certain that once the spade work has been carried out, these airplanes will not be any more costly than the same airplanes in wood. M. Amiot reckons that this initial outlay, despite an expenditure of 1,500,000 francs on machine tools, can be regained after the production of 100 machines. These figures may appear high, but they correspond to prices of new construction, and a considerable part of these machine tools can be utilized for the manufacture of other new airplanes, the construction of which is directly derived from the airplane D.1.C.1 Hispano.

I have only spoken up till now of metal construction in general, without going into details as to which metal aviation should call upon in preference. The issue can only fall on steel or on the high tensile light alloys of aluminum, more generally known under the name of "duralumin." Calculation would prove a priori for steel, on condition that it may be used for a load in the order of 90 kilograms. This, then, would necessitate the use of special steels, of which the machining is very

delicate; at least, to use them in the way that they are sent to us from the steel works there would be danger in working them without thermal treatment, and these treatments become impossible as soon as the pieces exceed a certain dimension. Your English firm, Boulton & Paul, have succeeded with some fine results in steel girder work, but I fear it would be very costly, and in any case, in France we have neither the steels nor specialists to undertake work of this kind. On the other hand, in the calculation of a structure one would not know the limits of sections, heads of rivets, and other metal parts which are not stressed, but of which the weight, in view of the density of steel, considerably increases the weight of construction.

For small airplanes, steel is, in our opinion, too heavy, and therefore calculated dimensions are often impracticable, because they do not give sufficient local rigidity. In the Jaguar "Siskin" and the "Fokker," only the fuselage is of steel. In the Dornier "Falk," the wing spars are of steel, but in no fighter airplane, for example, has the complete construction been in steel.

For large airplanes this disadvantage would certainly diminish, but it would nevertheless remain that the assembly rivets, for example, would have to be made in mild steel, while the struts would have to be in a special steel, hence the necessity to multiply the number of rivets, and thus increase weight or bad utilization of metal.

Finally, what I think to be a most important fact in the use of steel is that it does not permit us to consider solutions of the future problem of construction which I deem to be the logical end of our present studies - to have the integral metal airplane with a covering of metal taking a share of the stress. A covering of steel sheet of 4/10 average thickness would weigh already with the riveting about 6 kilograms per square meter of wing. This figure alone is prohibitive, because one would not think of using a sheet of such light gauge.

If, therefore, one imagines a steel wing, of which all the stresses would be taken in the covering, one sees that the thickness to which one would be forced to allow for the forces of bending and compression would lead to completely impossible weight.

The light alloys of aluminum have a sufficient strength which permits their use in airplanes of all sizes. Thanks to this low density, it is possible to keep throughout sufficient thicknesses avoiding secondary failures, which is very important in aircraft structures which fail by buckling. The use of metal coverings is possible from this moment, even when they have not been calculated to take a share in the load. When they are taken into the structure, one arrives at - depending on the dimensions of the airplane - reasonable weights of construction. For example, the fighting airplane Bernard, which is a monoplane of entirely cantilever construction, and is all-

metal, covering included, weighs $10\frac{1}{2}$ kilograms per square meter of surface, and gives a factor of 18 on static test. Comparison is made with my D.1.C.1., which weighs about 8 kilograms to the square meter, covering included, and shows a factor of 16 on such test. One sees that even on small dimensioned airplanes duralumin covering is not to be disregarded, and that on much larger airplanes it becomes extremely interesting.

Many constructors fear using duralumin on account of the necessity of treating it after each important factory operation. We must not exaggerate this obligation; many operations can be worked cold.

The metal "Schneider," for example, which was at the last French Exhibition, is one made entirely by cold working, without thermal treatment of any kind.

In my machines the members are developed in such a way as to use metal as delivered from the mill, and only worked parts need a thermal treatment.

However, if one is led to effect thermal treatment to facilitate work on duralumin, it is not a very grave difficulty, inasmuch as this metal being self-tempering, after tempering at 475° one has at one's disposal a certain number of hours (about four) for working it, and it will regain of itself its stable mechanical characteristics. The process which consists of re-heating duralumin to 350° to work it, would necessitate treatment after working.

Finally, from my own point of view, I must take account of the fact that aluminum is found in abundance in France, while there is a great scarcity of timber such as is used in aircraft work. There is, therefore, a material interest for French constructors to develop the use of duralumin in the building of aircraft, to avoid the necessity of our country being dependent upon foreign countries.

This is one of the reasons why French industry has been led by the official Services towards construction in duralumin. We are going to see how this has come about, and what is its actual evolution.

The use of duralumin already dates back a number of years, and the '14 Breguet, which was in use at the end of the war, was already a metal machine with the exception of the ribs, which were then still in wood.

At the beginning of metal construction we were content with substituting, piece for piece, metal for wood, in using the most common sections which were available.

This was the case in the Breguet '14, of which the spars were rectangular tubes in duralumin, and of which the fuselage was lattice-work of round duralumin tubes joined together by acetylene-welded steel sockets.

In the construction of the wing structure, the search for minimum weight led rapidly to the making of built-up spars, which alone permitted an economic distribution of material;

longerons in a double T, as in the Breguet '19, or in the box form, as in my machine D.1.C.1.

In this machine in particular, I have realized for my spars, forms of uniform strength, and I believe it would be difficult to get better results with the same weight in any other way.

This longeron is formed by two webs in sheet metal of 15/10 of variable height, assembled by the intermediary of angle sections with flanges formed of several thicknesses of sheet metal of varying number, according to the work it has to do, and of which the dimensions at the fitting of the strut are four thicknesses of 10/10 and one of 15/10 for the upper socket, and five thicknesses of 10/10 for the bottom socket.

This weighs 17 kilograms, and has withstood on test a distributed load of about 4,500 kilograms.

In these conditions the bending moment at the point of maximum stress, that is to say, at the attachment of the strut, is of 3,000 kilogram-meters. The section of the spar having 200 mm height and 100 mm width, the load factor of the metal is about 25 kg.

To resist this same effect a wooden spar of the same form, and solid, would give way at a load of 4.5 kg; it would not be able to stand the load.

Such a spar would, besides, be heavier than a duralumin one. To withstand this load in wood it would be necessary to

augment the dimensions, which could only be done in width, thus without any appreciable gain of inertia. It is even possible that one might arrive at an impossibility; thus the Nieuport fighter, at the last Aeronautical Show, had duralumin spars, probably because wooden spars, which are a tradition of this house, could not be employed.

For the ribs duralumin is equally advantageous, whether they be made of tubes, as in my fighter airplane, or in U sections, which are very much in vogue in France. An example will give you an idea. The experience of wooden construction has enabled the French Technical Services to establish an empirical formula giving the least weight of ribs per square meter of carrying surface in a well-made wooden machine.

This average weight is the following:

$\pi = K\,p\,l$ in which K is the index 1000 of the static test; p, the load per square meter; l, the depth of the wing.

In my fighter, $K - 16$, $p - 62$ kilos, $l - 2$. The formula thus gives $\pi = 1$ kilogram to the square meter.

Besides this, in my fighter airplane there are three ribs per meter, weighing on an average 500 grams for a wing chord of 2 meters.

The average weight to the square meter of rib is then only .750 kilograms, instead of that given by the formula. This advantage would be more marked with the size of machines if one could increase the length of the ribs without proportionately

increasing the dimensions of the tubes constituting them, and without losing any of the rigidity of these ribs, which could not be got in wooden ribs.

In all, the covering of the D.1.C.1., with its struts, weighs, without fabric, 140 kilograms per 20 square meters, and has stood 20 tons on sand test, while the wing structure of the "Nieuport" has a weight of about 190 kilograms for 26.5 square meters, and has only supported around 10 tons.

There is, therefore, bearing in mind the increase of strength, a very appreciable gain of constructional weight, for which I count the use of duralumin construction responsible.

For the moment, metal fuselages are generally made in girders, in trellis fashion. For the longerons, the uprights and cross-pieces, one uses either round tubes, rectangular ones (Liore Cam), T sections, or angles. The use of these last sections simplifies assembly but gives certain disadvantages. First, it is almost impossible to make the neutral axes meet the points of assembly, which prevents metal being used to the best advantage.

On the other hand, for parts in torsion, the round tube is much the better section, as the following test table shows:

Section	Measurements	Material	Weight per meter	Torque	Quotient of the torque by weight
Angle	35/35 thickness 35/10 length 900	Duralumin	657 gr	1100 kg	1670
Round tube	38/40 length 900	Duralumin	350 gr	2500 kg	7100
Solid wood rectangular	27/5 27/5 length 900	Spruce	355 gr	1300 kg	3650

This table shows the decided superiority of round tubes from the point of view of their resistance to torsion, and of general constructional weights.

Their assembly alone presents certain difficulties. Steel sockets acetylene-welded, type "Breguet '14" are heavy, and do not allow of replacements for repair. Besides, they introduce welding, which is not altogether safe, above all in mass production.

A careless workman may burn the metal, and no subsequent thermal treatment can regenerate such a dangerously fragile piece.

Recently M. Breguet invented for his machine "19 A.2" a very ingenious joint in forged aluminium, which is decidedly lighter than the steel one.

Thanks to a constructional contrivance, these joints are partly standardized, and two are sufficient in the whole fuselage.

But, in my opinion, I still prefer the joints of the "Societe d'Emboutissage et de Construction Mecanique," made in duralumin sheet, beaten out to the exterior form of the tubes as assembled, and joined by rivets.

These joints are very light, and particularly economical in quantity. Joints of this type are used in the construction of the tubular ribs of my machine "D.1.C.1."

Fuselage weights of this type are of the same order as those of the wooden fuselage of the same design, and often lighter.

In general, the latest achievement in France in metal airplanes, show the excellent results which can be obtained. These are, for example, the "Gourdou Lesseure" machines, with a height record, the famous "Breguet 19" flown by Pelletier D'Oisy and Arrachard, and the recent fighters "DeWoitine," "Spad" and "Gourdou." In such airplanes, performance is the essential quality, and our French authorities are unanimous in realizing that it is to the judicious use of duralumin alloys that they owe results which no one would venture to question.

These qualities of good performance have not prevented achieving a remarkable durability. The flight of Pelletier D'Oisy has shown the good constructional quality, which has withstood most rapid and important climatic changes. The very recent examinations of the Lemaitre and Arrachard airplanes have also confirmed the point. In the same way I had my air-

plane D.1.C.1. examined by the French Technical Services after 350 hours' flying. The condition of the framework was perfect, and no play or failure of rivets had occurred. These reports confirmed my confidence in the use of duralumin. This confidence is now being shared by our "navigation" companies, and M. Latecoere in particular, whose air lines cross countries with greatly-differing climates, shares this conviction based on many years' experience. The Breguet '14 machines which he uses, have no wood in them except for the ribs; further, he has proved the necessity to change these after a limited number of trips, while all the rest of the metal framework needs no special repair.

That is why I believe in the future of the all-metal airplane, in which one will have effectively realized an entirely homogeneous construction by the suppression of linen coverings in particular, and by the realization of rigid structures which are not liable to become warped or out of truth.

This construction will facilitate the creation of very efficient wing structures, cantilever monoplanes, or biplanes with rigging reduced to a minimum.

On the other hand, such airplanes will have a uniform modulus of elasticity, the metal resisting the same stress in all parts, and thus only will it be possible to allow a low coefficient of safety for known stresses undergone during flight.

But such a construction necessitates a complete modifica-

tion of our present ideas of framework.

It is very evident that we shall not be able to retain for the wings, for example, the standard system of two longerons cross-braced, with ribs supporting the covering; in the same way the trellis fuselage would badly adapt itself to a covering taking any part of the load.

In this domain I have on my own account worked especially on a metal shell, and the results I have obtained are most encouraging. With frames and longerons conveniently distributed, a covering sheet of 5/10, the shell of my D.1.C.1. weighs, with its engine housing, 80 kilograms.

This shell is thus light, and presents advantages of indeformability which are extremely interesting. Besides, in case of accident, such a shell will bend without breaking, and this can be considered as a good protection for the equipment, while in a hull or fuselage of wood fractures and dangerous splinters of wood would result.

The involuntary test of this was made by two French military pilots, who came safe and sound out of my machines after accidents on taking off and landing which would have been serious if they had been in any other type of construction.

The problem I see from now onwards (that of fuselages being settled) is that of wings, on account of the great difficulties involved. The compressive forces withstood by wings are incomparably higher than those of fuselages, and that is

why constructors have met with quite considerable difficulties in the realization of an all-metal wing within compatible limits of weight and performance.

For some years Junkers has made machines in such a manner, and the results he is obtaining are satisfactory. However, if the idea he has adopted for the framework of the wing is to me quite all right, it nevertheless presents difficulties with the joints between the longeron tubes and the bracing members. The use of the methods of assembly of the S.E.C.M. type would certainly greatly help the production.

In France, Latecoere, Schneider, Bernard and Wibault have overcome the problem with different solutions.

The idea of girder wings of the designer, Hubert, who builds the Bernard airplanes, seems to me to be the most interesting and susceptible of great development in the future.

Whatever solution may prevail after years of necessary study, I have faith in all-metal construction, at least for airplanes of large tonnage, which without a doubt become the commercial machines of the future. Wood will still remain the material for touring machines, and for those of low power it will also be very much used, as I have used it myself for the rapid study of prototypes; but I cannot conceive that the ultimate airplane can be in anything else but metal, in the same way that metal ships today completely replace the wooden ships of days gone by.

You Englishmen, with your powerful metal and mechanical industry, are better fitted than no matter who to collaborate in this necessary study. Having no particular bias, I should be happy to see you freely undertake the study of duralumin for airplane construction.

I believe the suspicion you have had up till now for duralumin is not justified, and that those among you who have begun to use it will rapidly be convinced that such is the case.

Neighbors as we are, exchanges of ore and finished metal could but still further draw the commercial bonds together, and the technical construction which your experience would bring us would be infinitely precious to us.